



Metamaterial based split triangular shape microstrip antenna

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General Note

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ABSTRACT

Present paper is based on improvement in gain and the profile of triangular microstrip antenna using metamaterial structure. Widely used metamaterial, engineered for specific purposes, have negative permittivity (ENG) or negative permeability (MNG), or both negative (DNG) with negative refraction coefficient. Author is discussed the antenna with left handed metamaterial (DNG) based structure to enhance the antenna efficiency, reduced the return loss to increase the bandwidth at the same resonant frequency. Simulation is done by using commercial software HFSS, based on finite element method (FEM) and compared with results, obtained from coding. Both obtained results are in close agreement within ~5%. Author is also shown the improvement in gain and bandwidth of simple triangular antenna after using the metamaterial based split ring triangular shape antenna with the help of plots.

Keywords: Triangular microstrip patch antenna, left handed metamaterials (LHM), return loss, VSWR, bandwidth, HFSS simulation software.

1. INTRODUCTION

Metamaterials are materials designed to have a specific properties that have not been found in nature yet. It is used for special purposes to reduce the losses as well as to improve the efficiency as well as validity of the designed structure. It can be applicable for various frequency ranges upto Terahertz frequencies. Metamaterials are combination of different multiple elements, but properties of these materials cannot be described by the base composite elements but from the structure of materials. These materials are usually arranged in periodic pattern which repeated itself after some periodicity and the size of repeated structures are smaller than the wavelengths of the phenomena they influence. Appropriately designed metamaterials can affect electromagnetic radiation or sound, which is not found in bulk materials. Basically, metamaterials are divided into two major categories, resonant and non resonant types, depends upon the oscillation of waves as well as periodicity of structures. Resonant types of metamaterials have well specific permittivity and permeability, which further divide it into sub categories. Double negative (DNG), negative permittivity (ENG), negative permeability (MNG) and negative refractive index types are the widely used resonant type metamaterials, whereas anisotropic and hyperbolic are the non resonant type metamaterials, which have certain specified bands for electromagnetic waves. Today's, metamaterials based structures are more commonly used in waveguides, antennas design, filters design and lots of other applications. Left handed metmaterials (LHM), which has negative permittivity and negative permeability is also known as DNG materials, are used for design of coplanar waveguides, filters (low pass, high pass) and microstrip lines (Antennas). LHM based microstrip antennas have high efficiency, low profile and high bandwidth which is broadly usable in wide band applications. Simple microstrip antennas have radiation not only from patch, but also from substrate material that support patch and ground plane, which is basically a surface waves which creates radiation losses. So, the antenna has low bandwidth, low efficiency, poor directivity as well as higher losses. These losses can only be reduced by keeping the values of permittivity and permeability as low as possible. In this case, metamaterials help to remove such problems. By the same time, non resonant type metamaterials under which photonic band gap (PBG) or electromagnetic band gap structures (EBG), play an important role to achieve higher bandwidth with greatest potential applicability in broadband communication systems. These PBG structures have smaller size which varies in sub wavelengths as well as have a greatest tolerance value to resist the structural deformations. PBG structures have magical properties than resonant metamaterials with periodicity $\sim \lambda/4$, whereas resonant metamaterials have periodicity $\sim \lambda/10$. For 5G mobile communication, PBG structure is more valid for high bandwidth and can be applicable with antenna design in mm-wave technology, where it will for 30 GHz to 300 GHz frequency range. Plane waves with photons enter into the band gap (stop band), coming after finding the dispersion diagram for getting the cut off frequency with phase constant. Metamaterials is also for artificial magnetic conductors. Negative refractive index metamaterials is used for incident waves which have propagation faster than light propagation and for angle insensitive devices.

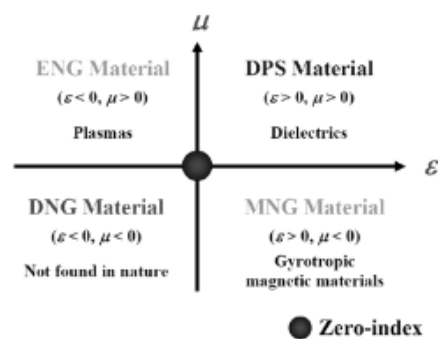


Figure 1 Classification of metamaterials on the basis of their permittivity and permeability [1]

Figure 1, shows the classification of metamaterials of resonant type, where each and every coordinate represents the metamaterials on the basis of their permittivity and permeability, having negative or positive values, separates from each others. LHM is used in third coordinate system, having both negative values with negative refractive index, and not positive as well as negative thickness of structure which is used for antenna design purposes. These properties are based on Maxwell's equations, which give the proper information about DNG materials.

2. ANALYSIS

There are so many models, which describe the how metamaterials works and about negative permeability and permittivity of that material. One of the famous models, given by Lorentz, is most usable and known as Lorentz oscillator model. Without electric fields and magnetic fields, electronic charges, ions etc. have not any specific direction. After applying electric fields or magnetic fields, they become polarized and that displaced the electron clouds. One equation which is valid for electromagnetic waves is used here, to show the motion of electron in the material. As given in equation (1), first term in left hand side is inertia, second term is loss and third term is restoring force, whereas, in right hand side denotes the applied electric fields. Now, due to these term, electron gets polarized and starts work according to electrical force and its combined with the wave which is out of phase, and generates oscillation.

$$m \frac{\partial^2 r}{\partial t^2} + m\Gamma \frac{\partial r}{\partial t} + m\omega_0^2 r = -qE \quad (1)$$

The split ring triangular antenna, produces magnetic material like response and exhibits negative permeability, which shows the plasmonic type of frequency in the form of [2, 3, 4],

$$\mu(\omega) = \mu_0 \left(1 - \frac{\omega_{pm}^2}{\omega(\omega - j\Gamma_m)} \right), \quad (2)$$

Where, ω_{pm} = Magnetic plasma frequency, Γ_m = Damping coefficient, μ_0 = Permeability in free space.

Negative permeability is also come when, $\omega < \omega_{pm}$. On the other hand, capacitive loaded structure is responsible for negative permittivity due to strong dielectric exhibits by this structure [5]. This conditions generate an electric dipole moment in the structure and exhibits the plasmonic type of permittivity frequency in a function of [6, 7],

$$\varepsilon(\omega) = \varepsilon_0 \left(1 - \frac{\omega_{pe}^2}{\omega(\omega - j\Gamma_e)} \right), \quad (3)$$

Where, ω_{pe} = Electric plasma frequency, Γ_e = Damping coefficient, ε_0 = Permittivity in free space.

This structure would also give negative permittivity at, $\omega < \omega_{pe}$. Equations (2) and (3) are derived using Lorentz oscillator model. But, there is one more models, Drude model for metals is widely used and easy to apply for finding out the negative permittivity and permeability [8]. This equation (4) does not have any restoring force part in left hand side, means electron are not bound, so the restoring force is equal to zero.

$$m \frac{\partial^2 r}{\partial t^2} + m\Gamma \frac{\partial r}{\partial t} = -qE, \quad (4)$$

Using equation (4), negative permittivity and permeability can be calculated, which would be function of frequency, widely known as dielectric functions.

$$\varepsilon_r = 1 - \frac{\omega_p^2}{\omega^2 + j\omega\Gamma}, \quad (5)$$

$$\omega_p^2 = \frac{Nq^2}{\varepsilon_0 m}, \quad (6)$$

Equation (5) is used to calculate the permittivity of material according to Drude model, whereas plasma frequency is related to total number of charges or electron cloud, which is given equation (6).

Basically, LHM is based upon Maxwell's equations ($\nabla \times E = -j\omega(-\mu)H$) and ($\nabla \times H = j\omega(-\epsilon)E$), which properly used and give a proper directions of magnetic field, electric field as well as polarization. Power and phase are in same direction and polarization is just opposite of fields which gives negative refractive index. Due to causality, poynting vector corresponds to forward travelling energy which is just opposite of power and phase, produces losses that can be minimized by using special type of structures, split ring is one of the widely structures in metamaterials. Due to negative refractive index, structure behaviour is changed just opposite of snell's law. So, the waves travel, have two main components, evanescent and oscillatory, in which evanescent component grows higher as compared to oscillatory component in LHM.

3. RESULTS AND DISCUSSION

The proposed structure is mend for Wi-Max band (2-6 GHz) with complex geometry as well. The structure containing a different materials and their properties to find the metamaterial characteristics. As, metamaterial (LHM) has negative epsilon and negative permeability, the structure is restricted for its design frequency. Metamaterial based antenna can work in microwave ranges as well as mm-wave frequency ranges, but mm-wave is basically useful for 5G cellular systems, so by observing the performance of antenna in Wi-Max band, one can apply this concept for high frequency range. Here, to design the structure and to obtained the results, commercial software HFSS and Matlab code are being used.

Table 1 is basically mentioned the parameters and material used for designing this antenna.

Table 1 Design specification of Antenna

Parts of Antenna	Material used	Parameters
Substrate	FR-4	Height = 3.4 mm,
Patch	Copper	Height = 3.4 mm
Ground	Perfect Electric	L = 70 mm, W = 45 mm
Transmission Line	Copper	Calculated using equations

From the Fig.2, the design of antenna with triangular shape has shown, where it is cleared that the metamaterial based antenna has open type structure and be restrict for some common well known structure.

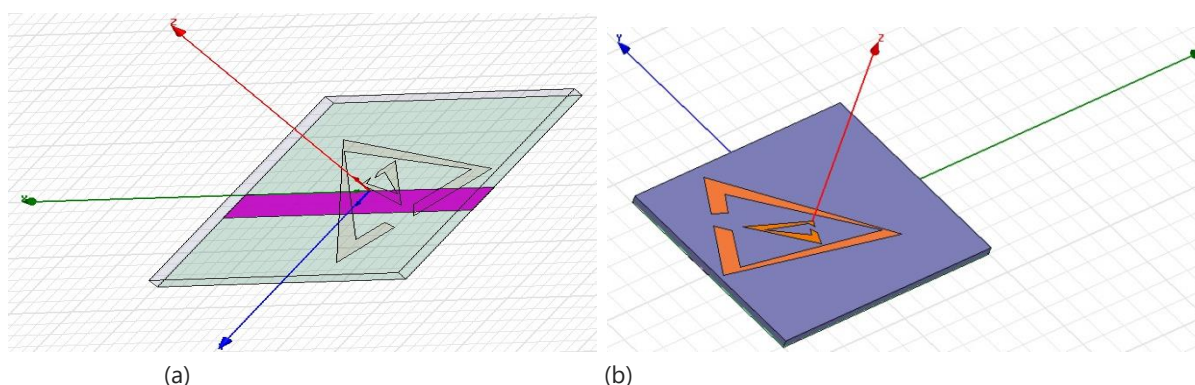


Figure 2 Antenna with excitation port and all other parts (a), Schematic of proposed antenna (b).

Main important part of proposed antenna is permittivity and permeability in given design frequency range, which will be negative for your specified frequency. Figure 3 is showing that permittivity and permeability of proposed antenna is going down negative with frequency, which has positive refractive index and it will just the behaviour like in Fig. 1.

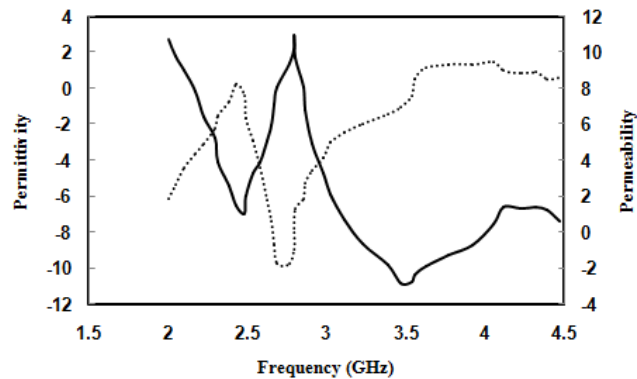


Figure 3 Permittivity (dotted line) and Permeability (solid line) of metamaterial for designed frequency.

At frequency 3.6 GHz, which is got shifted from design frequency 3.5 GHz, the plot is showing negative behaviour for permittivity and permeability.

Figure 4 and 5 are showing the scattering matrix parameter in terms of return loss (S11) and VSWR of the proposed antenna. One can easily see that at frequency, 3.6 GHz, return loss is approximately is -28 dB and VSWR is 0.6. Practically, VSWR should lie in between 1 to 2, but it is lesser than this practical accord, this is because of some mismatching of external component with antenna structure and surface wave radiation which is involved to substrate. Bandwidth of designed metamaterial based antenna is 0.2 GHz, which is suitable for 4G applications.

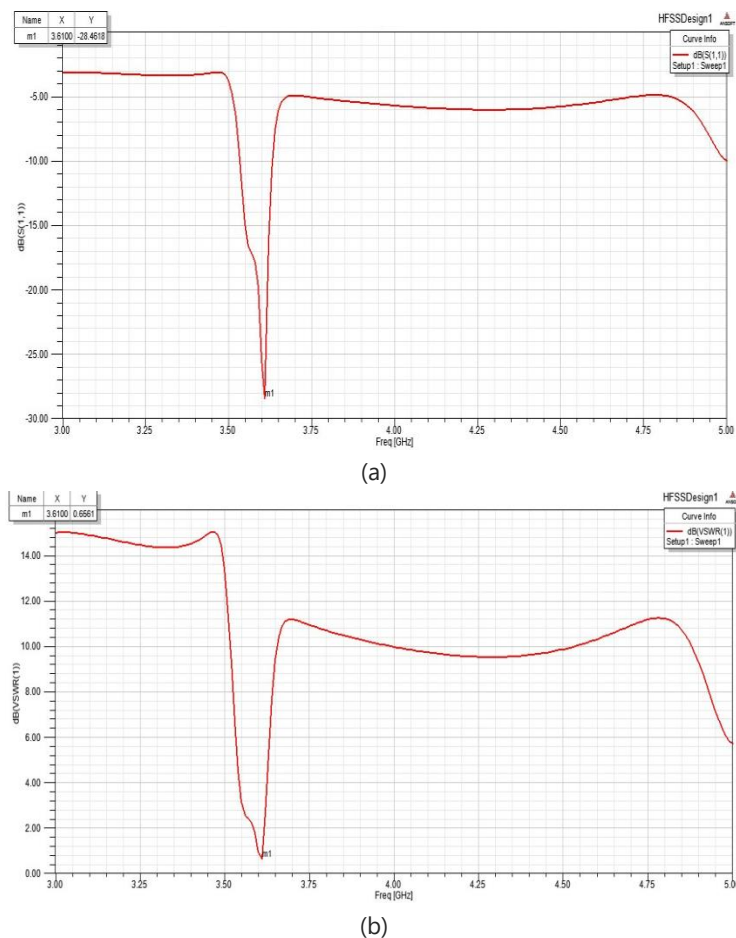


Figure 4 Return Loss (S11) (a), VSWR (b) for proposed antenna.

Radiation pattern is one of the most important parameter for antenna design to verify its applicability in terms of electric field, magnetic field, gain, directivity and power spectral density. Here, in Fig. 5, first far field pattern is for directivity for antenna and second one is for electric field for theta variations. The directivity of antenna is measured as 65 dB, which explain how much directive antenna is.

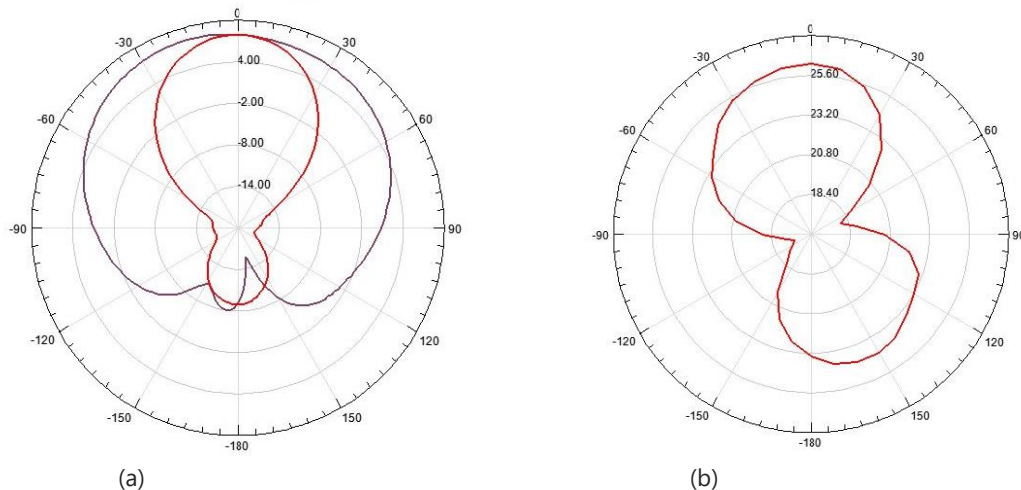


Figure 5 Directivity in terms of radiation pattern (a), Electric field profile in terms of radiation pattern (b).

4. CONCLUSION

The metamaterial based triangular antenna is simulated for obtaining the return loss, VSWR, permittivity, permeability and its directivity. Return loss for proposed antenna is -28 dB, which is good as compared to simple triangular antenna. From obtained plots, it is cleared that if this antenna is working for 3.6 GHz frequency, then by increasing the frequency range, up to mm-wave, the proposed antenna will work for 5G networks only to change in design from single patch to array of patch or MIMO based designed. Negative epsilon and permeability helped to improve the frequency range so that band width could increase for getting more number of users in a single channel.

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